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SOME CHARACTERISTICS OF THE RAINFALL OF THE UNITED STATES

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Annual and Monthly Variability of Rainfall.—The amount of precipitation which occurs in a year is variable, because the rain-producing conditions, such as the number, intensity and paths of cyclones, and the general pressure distribution, vary more or less from year to year. A close study of the daily weather maps usually shows why a given station or district had a wetter or a drier year than normal. It is important for many persons, notably farmers and engineers, to be informed concerning the probable limits of such variations. The following table shows the ratios of the rainfalls of the wettest and driest years to the mean annual rainfalls for selected stations throughout the United States.[1]

Ratio of Wettest and Driest Years to the Mean Fall

Mean Fall Inches	Average of Wettest Year, Per Cent.	Average of Driest Year, Per Cent.
50–60	142	70
40–50	143	64
30–40	154	64
5–30	178	55

To state these relations verbally: an annual rainfall of nearly 180 per cent. of the mean may be expected in districts with mean annual rainfalls of 5–30 inches. In these same districts the rainfall of the driest years averages only slightly over one half of the mean. It will be observed that the departures from the mean average greater where the annual amounts are smaller.[2] Furthermore, there may be a succession of several years with an excess or a deficiency. During 1869–1903, considered by 5-year periods, a total of 119 stations in the

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[1] Alfred J. Henry, "Rainfall of the United States, with Annual, Seasonal and Other Charts," *Bulletin D,* U. S. Weather Bureau, 4to, Washington, D. C., 1897, p. 41.

[2] See also A. R. Binnie, "On Mean or Average Annual Rainfall and the Fluctuations to which it is Subject," *Proc. Inst. Civ. Eng.,* Vol. 109, 1891–92, Pt. III., London, 1892 (average limits for wettest and driest years in North America are 141 per cent. and 68 per cent., as quoted by von Hann, "Lehrbuch der Meteorologie," 3d ed., p. 332).

"arid region" showed an excess in average annual rainfall, and 150 showed a deficiency.[3] It appears to be a general rule that years with precipitation above the mean are less frequent than those with precipitation below the mean. The plus departures are therefore greater than the minus departures.[4] Remarkable cases of great differences between the rainfalls of consecutive years are on record. Thus, on Mt. Hamilton, Cal., 90.1 inches of rain and melted snow were measured in 1884, and only 18.4 inches in 1885.[5] Many illustrations, although few as striking as this one, may be found in the records of the Weather Bureau.

The rainfall of any individual month may also differ greatly from the normal of that month. Many illustrations of this variability of the monthly means of rainfall might be given. The Weather Bureau records supply abundant data for the study of this subject. In a certain September, *e. g.*, when three cyclonic centers passed over the South Atlantic States, the average rainfall for the district was 9.47 inches, while in the same month in another year, when no storm center crossed the region, the average rainfall was less than one fifth (1.84 inches) as large.[6] It is always instructive to investigate the weather map conditions which give rise to unusually wet or dry months. The prevailing winds and the pressure distribution during a wet and during a dry winter month on the Pacific coast have been charted by Henry.[7] The abnormally rainy month was clearly due to the displacement, to the south of their usual latitudes, of the tracks of the low pressure areas. The amounts of rainfall along the coast north of San Diego were in most places over twice the normal, and in the Colorado region, where the monthly mean is less than 2 inches, this particular month gave over 10 inches. Unusually heavy monthly rainfalls over the plateau are almost always due to persisting cyclonic conditions west of the Rocky Mountains. In the dry month, the tropical high pressure system was abnormally far to the north, and the rainfalls averaged about half the normal amount. The prevailing pressures and winds in a wet and a dry March in the Mississippi Valley have also similarly been considered by Henry,[7] and McAdie has charted the typical pressure distribution and flow of winds during a wet and a dry winter month in California.[8] The former had low pressure over the northwestern coast, with prevailing southerly (*i. e.*, rainy) winds, while the latter had high pressure over the northern Plateau, with prevailing northerly (*i. e.*, dry) winds.

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[3] William B. Stockman, "Periodic Variation of Rainfall in the Arid Region," *Bulletin N*, U. S. Weather Bureau, 4to, Washington, D. C., 1905, p. 6.

[4] An earlier table showing the mean annual deviation of rainfall at selected stations in the United States, as determined by Blanford's method, will be found in Gen. A. W. Greely's "American Weather," 8vo, New York, 1888, p. 154.

[5] See footnote, 1, p. 23.

[6] "American Weather," p. 148.

[7] See under footnote 1, Charts IV., VI., VIII., X., pp. 23–24. Also "Atlas of Meteorology," Text, p. 35, Pl. 24.

The fluctuations of the monthly rainfalls at New York during the period 1871–1900 have been investigated by Wachenheim.[9] Three times in ten years a month occurs with less than 25 per cent. of its mean, usually in September and October. About twice as often the rainfall of a month is over 200 per cent. of the mean, mostly in summer and autumn. In 70 per cent. of all months the amount of rainfall is less than 50 per cent. above or below the normal. The annual means vary between 80 and 130 per cent. of the normal. The mean annual variability is only 9 per cent. At San Francisco it is 25 per cent.

Consecutive Days with and without Precipitation.—The maximum number of consecutive days that have been recorded as passing with, and without, rain or snow, is a matter of considerable general interest. These data do not, of course, indicate that such rainy or rainless periods occur annually, but they represent the maximum duration of these conditions within the years covered by the observations.[10] Over most of the country, the number of consecutive rainy days has been between 10 and 20, these conditions characterizing by far the larger part of the districts east of the Rocky Mountains except the southern Great Plains (Texas). On the northwestern coast (western Oregon), where the rainfall is heavy and the cyclonic activity is marked, more than 30 days in succession (30–40) have been rainy, while over a considerable area centering around the Great Lakes the number has been 20 to 30. The frequency of cyclonic rainfall in this latter section, and not the annual rainfall, clearly controls the conditions. The districts of heavier annual precipitation north of the Gulf of Mexico have had fewer consecutive days with precipitation than the Lakes. Adjoining the district of the maximum number, on the northwestern coast, a considerable area, including part of northern California, eastern Oregon, most of Washington and Idaho, has had 20 to 30. The smallest number of consecutive days with rain or snow (less than 10) has occurred in southern California, over much of the Southern Plateau province, and over most of central and western Texas.

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[8] Alexander G. McAdie, "The Rainfall of California," *Univ. of Cal. Publs. in Geogr.*, Vol. I., No. 4, February, 1914, Figs. 1–2, pp. 131–132.

[9] F. L. Wachenheim, "Die Hydrometeore des gemässigten Nordamerika," *Met. Zeitschr.*, Vol. 22, 1905, pp. 193–211.

[10] Mark W. Harrington, "Rainfall and Snow of the United States," *Bulletin C*, U. S. Weather Bureau, Washington, D. C., 1894, *Atlas*, Sheet XXII., Charts 9, 10; *Text*, pp. 28–29. (These charts were based on about twenty years of observations, and are the latest that are available. They are, therefore, not up to date, but are doubtless correct in general terms, and would not be materially altered by the addition of newer data.)

From two weeks to a month (15–30 days) have elapsed without precipitation over most of the Eastern Provinces, and from one month to two months (30–60 days) over most of the Plains, the Northern Plateau and the North Pacific provinces. The duration of rainless periods increases rapidly from all sides towards the arid districts of the southwestern interior, where over five months (150 days) have passed without rain or snow. Clearly, then, the duration of rainless periods is least where the rainfall is heavier, the distribution through the year is more uniform, and the cyclonic activity is greater

Droughts.—Long periods without rain are generally classed as droughts. The term connotes a long spell of dry, but not necessarily altogether rainless, weather, resulting in damage to crops. A clear-cut and comprehensive definition of a drought is, however, difficult to frame, for the reason that the effects depend so largely upon other factors than the deficiency of rainfall. Thus, the accompanying temperatures; amount of wind movement; character and condition of the soil; evaporation; cloudiness; stage of the crop, and other varying controls, enter into the problem. If a drought is arbitrarily expressed in terms of a deficiency in annual, or seasonal, or weekly rainfall of a certain percentage, it may appear that in two districts which have the same deficiency, the effects are different because the other controlling factors are not the same. Droughts of greater or less intensity may occur anywhere in the United States, but are more likely to be serious where the annual rainfall is small, and where cyclonic controls of precipitation are weak. Weather-map conditions during droughts as a whole show that the immediate meteorological controls are weakened cyclonic activity, or somewhat unusual cyclonic paths, or both. Special studies have been made of various severe droughts in the United States.[11] An economic aspect of droughts to which special attention has recently been directed is that of their relation to the occurrence of forest fires. "A prerequisite of a forest fire is a drought."[12]

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[11] See, *e. g.*, A. W. Greely, *loc. cit.*, pp. 246–250; Alfred J. Henry, "Climatology of the United States," *Bulletin Q*, U. S. Weather Bureau, 4to, Washington, D. C., 1906, pp. 51–56; "Rainfall of the United States,"

Additional Rainfall Data: Hourly Frequency of Rainfall.—A study of the distribution, intensity and frequency of rainfall brings out many interesting human relations, but the investigation involves much time and has so far received comparatively little attention in the United States.[13] The most complete studies of the details of rainfall in this country are those for Baltimore and for Chicago.[14] The economic importance of rainfall makes it highly desirable that many more such detailed studies should be undertaken. For example, if the hourly frequency of rainfall in the different months be known, it may be possible to plan outdoor work for the hours when there is the least likelihood of rain. Kincer has shown that over the Central Plains the greatest concentration of night rains occurs in the harvesting and threshing season, daytime rains being then comparatively infrequent.[15] The fact that the summer showers

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Bulletin D, U. S. Weather Bureau, 4to, Washington, D. C., 1897, p. 18. A map of the eastern United States showing the frequency of dry spells in the months of April to September during twenty years was published in the *National Weather and Crop Bulletin* for May 4, 1915. The greatest frequency was in the Plains province; the least in the southern Appalachians.

[12] E. A. Beals, "Forecasts of Weather Favorable to an Increase of Forest Fires," *Proc. Second Pan Amer. Sci. Congr.,* Dec. 27, 1915, to Jan. 8, 1916, Vol. 2, Section 2: Astronomy, Meteorology, and Seismology, pp. 257–270, Washington, D. C., 1917.

[13] For a discussion of the rainfall data which are necessary in a full description of any climate, see J. von Hann: "Lehrbuch der Meteorologie," 3d ed., Leipzig, 1915, pp. 324–361. Also, "Handbuch der Klimatologie," 3d ed., Vol. 1, 8vo, Stuttgart, 1908, pp. 60–67.

[14] Oliver L. Fassig, "The Climate and Weather of Baltimore," *Maryland Weather Service,* Vol. II., Large 8vo, Baltimore, Md., 1907, pp. 159–237; Henry J. Cox and John H. Armington: "The Weather and Climate of Chicago," Large 8vo, Chicago, Ill., 1914, pp. 151–236. An earlier volume, still of importance in rainfall studies in the United States, is C. A. Schott, "Tables and Results of the Precipitation in Rain and Snow in the United States; and at Some Stations in Adjacent Parts of North America and in Central and South America," *Smithson. Contrib.,* No. 222, 4to, Washington, D. C., 1872; 2d ed., *ibid.,* No. 353, 1881. See also F. L. Wachenheim, "Die Hydrometeore des gemässigten Nordamerika," *Met. Zeitschr.,* Vol. 22, 1905, pp. 193–211. (Discussion of data for 1871–1900, including rain intensities for different districts.)

[15] Joseph B. Kincer, "Daytime and Nighttime Precipitation and their Economic Significance," *Mo. Wea. Rev.,* Vol. 44, 1916, pp. 628–633. (Hourly amounts and frequency are shown by diagrams. Three charts give the average precipitation for the United States in inches during the day, 8 A.M. to 8 P.M., and night, 8 P.M. to 8 A.M., for April–September,

are chiefly nocturnal means that evaporation is less than would be the case under sunshine. Daytime rains are dominant in the southeast and along the immediate Gulf coast. Over portions of the southeastern states only about 25 per cent. of the summer rainfall (April–September) falls at night, while on the Central Plains from 60 to 65 per cent., or more, falls during that time. At Columbus, O., 42 per cent. of the precipitation of the growing season (April–September) is recorded at night.[16] At New Orleans, La., in summer, the percentages of day rains as compared with those falling during the night range from 75 to 85.[17] Most of the summer rains are thunderstorm rains. At Galveston, Tex., convectional summer rains occur most frequently at night, and mostly in the latter part of the night.[18]

At Baltimore, the winter and spring months are characterized by a rather uniform distribution of precipitation throughout the day and night, in consequence of the uniformity of the cyclonic control, while in summer, a maximum occurs about 5 P.M., under the influence of thunderstorms.[19] At Chicago, also, the times of greatest hourly rainfall are related to the times of thunderstorm occurrence.[20] The hourly frequency of precipitation is greatest in the colder months.[21]

At Washington and New York the largest amount of rain falls between 2 and 4 P.M., and the smallest between midnight and 2 A.M. The rain frequency is greatest from 4 to 10 A.M.[22]

The mean hourly intensity of rainfall at New York, as given by von Hann, shows a maximum between 3 and 6 P.M. and a minimum between 3 and 6 A.M.[23]

Heavy Rainfalls in Short Periods.—Mean or average rainfalls do not often occur. An excess or a deficiency is much

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1895–1914, and also the percentage of the average precipitation for the same months that occurs at night.)

[16] Howard H. Martin, "Hourly Frequency of Precipitation in Central Ohio, and its Relation to Agricultural Pursuits," *Mo. Wea. Rev.*, Vol. 46, 1918.

[17] E. D. Coberly, "The Hourly Frequency of Precipitation at New Orleans, La.," *ibid.*, Vol. 42, 1914, pp. 537–538.

[18] W. P. Stewart, "Midsummer Showers at Galveston, Tex.," *ibid.*, Vol. 41, 1913, pp. 1225–1226.

[19] *Loc. cit.*, footnote 14.

[20] *Loc. cit.*, footnote 14.

[21] See also George W. Mindling, "Hourly Duration of Precipitation at Philadelphia," *Mo. Wea. Rev.*, Vol. 46, 1918, pp. 517–520.

[22] "Tables of Average Hourly Precipitation at Washington, D. C. (1874–1891) and at New York (1870–1891)," *Mo. Wea. Rev.*, Vol. 20, 1892, p. 79. Also, *Met. Zeitschr.*, Vol. 9, 1892, p. 480.

[23] *Lehrbuch der Meteorologie*, 3d ed., p. 345. See also, A. W. Greely, *loc. cit.*, pp. 155–156.

more probable than the normal. Hence there is need of knowing something about the maximum amount of precipitation which has occurred, and which is therefore likely to occur again, or may even be exceeded. The maximum amount of water which dams, sewers and supply-pipes may at some time or other have to take care of is of vital concern to engineers. Farmers, too, are interested in this matter, because of the washing and flooding character of very heavy rainfalls.

Excessive precipitation may result either from short and heavy, or from lighter but longer continued rainfalls.[24] Rains of the former type do the most damage. These occur characteristically over the western mountain and plateau districts, and are therefore seldom recorded. The torrential downpour ("cloud-burst") on the distant, uninhabited mountain slope; the sudden rise of a stream in its narrow canyon; the rush of the flood downward with irresistible force—these are familiar phenomena to many who have sought their livelihood in that rugged country. In the eastern United States, excessive rains of this general type occur chiefly in summer; are associated with thunderstorms or with West Indian hurricanes, and are found chiefly along the southern Atlantic and Gulf coasts. Rains of lighter intensity and of longer duration, of the second type mentioned above, occur in connection with general storms of unusual development, and are therefore found in the sections most frequently crossed by such storms, in the eastern and northeastern portion of the country, and on the northern Pacific coast. As pointed out by General Greely, the conditions which give rise to such excessive rainfalls are not likely to last long. These heavy downpours are therefore usually over within a day or so.[25]

Where the line between damaging and favorable rainfalls shall be drawn depends upon a large number of factors, such as topography, soil, condition of crop, etc. Complete data concerning excessive rainfalls for the year, month, day and shorter periods, are regularly published in the *Annual Reports of the Chief of the Weather Bureau* and in the *Monthly Weather Review*. Numerous other tables of heavy precipitation, and several discussions of these data, have been published in recent years.[26]

[24] A. J. Henry, "Rainfall of the United States," *Bulletin D*, U. S. Weather Bureau, 1897, pp. 52–54.

[25] A. W. Greely, *loc. cit.*, p. 148.

[26] See, *e. g.*, A. W. Greely, *loc. cit.*, pp. 144–150 (details of excessive rainfalls up to date of publication); Mark W. Harrington, *loc. cit.*, Text, pp. 27–28, 59–80; *Atlas*, Sheet XXII., Map 8 (discussion of heaviest rain-

In a general description of climate, the actual "record" rainfalls are of no special concern. The maximum changes as the length of the period of observation lengthens. "Records" are thus constantly being "broken." The absolute maximum hitherto noted is, therefore, a rather accidental matter at best, and it is hardly worth while, in a general account, to remember single "records" which are, at any moment, likely to change. For the present purpose, broad generalizations, easily remembered, are sufficient.

As a convenient rough-and-ready classification the following rainfalls may be termed excessive: 10 ins., or more, in a month; 2.50 ins., or more, in 24 consecutive hours; 1 in., or more, in an hour. It must, however, be noted that these amounts are often reached and exceeded, and are in no way to be regarded as unusual in many sections of the country. They are especially likely to occur along the southern Atlantic and Gulf coasts in the warmer months, and on the Pacific coast in winter. An examination of the available data regarding the heaviest rainfalls in the United States leads to the following simple general statement, which covers the ground fairly satisfactorily and will need no essential modification as the length of the period of observation increases. An average of 1 in. a day, for 30 days, giving 30 ins. in a month, is not often exceeded, although there are a good many cases of still heavier monthly rainfalls, and one case of over 70 ins. (Helen Mine, Cal., January, 1909). A fall averaging 1 in. an hour, for 24 hours, covers the heaviest daily rainfalls thus far recorded, the absolute maximum being 22.22 ins., at Altapass, Mitchell Co., N. C., July 15, 1916. It is impossible to give any rate of rainfall covering, in a similar simple way, the amount of precipitation in spasmodic, torrential downpours which may be over in half an hour, or in even less time. In a "record" cloud-burst (Campo, Cal., August 12, 1891) 11.50 ins. fell in 80 minutes. This was at the rate of a little over 8.50 ins. an hour, continued for 1 hour and 20 minutes. In some of these "cloud bursts" the rate has actually been as high as 16–18 ins. an hour, but

falls, including heaviest rainfalls at selected representative stations for year, month, 72, 48 and 24 hours, with tables); A. J. Henry, *loc. cit.*, pp. 52–58; "Summaries of Climatological Data by Sections," *Bulletin W*, U. S. Weather Bureau, 1912, and later reprints of various sections. A recent discussion and tabulation of data, mostly for the period 1896–1914, will be found in Adolph F. Meyer, "The Elements of Hydrology," 8vo, New York, John Wiley and Sons, 1917, pp. 64–187. (Includes data for typical excessive rain-storms; illustrated by numerous curves and charts.) See also C. A. Schott, *loc. cit.*, footnote 14.

continued for very short periods. In view of the "patchiness" of the records of heaviest rainfalls, it hardly seems worth while to chart them for the country as a whole, although Harrington prepared such a chart in 1891.[27] From this chart it appears that, not taking account of the mostly unrecorded local cloudbursts of the West, daily rainfalls approximating and even exceeding 10 ins., have occurred over a relatively narrow strip along the southern Atlantic and Gulf coasts, and were associated with the passage of West Indian hurricanes. To the north and west the maximum daily rainfalls as a whole decrease in amount, increasing again on the northern Pacific coast, but without equalling those of the southeastern sections.

Secular Variation in Rainfall: Instrumental Records.—Popular belief in a "change" of climate goes back to the early decades of the settlement of the United States, and frequent mention of the subject occurs in the literature. In the '70's and early '80's a widespread interest developed in the question because of the impression, which rapidly gained ground, that the building of railroads, the construction of telegraph lines and the ploughing of the soil over the western Plains were gradually bringing about a progressive increase in the rainfall over those sections of the country. Popular interest in the matter naturally led to a critical examination of the then available rainfall records, and several studies were, at that time, made along this line.[28] No definite evidence of any progressive secular variation in rainfall was found, in these, or in other early investigations of a similar sort.[29]

It is upon the evidence furnished by accurate instrumental records, and not upon tradition, or human memory, or uncertain evidence of other kinds, that reliable conclusions in this matter must be based. The period covered by rain-gauge records in the United States is a comparatively short one. Few observations go back of 1850, and most of them date from later than 1870. There have thus far been few noteworthy studies of these records from the viewpoint of their relation to climatic "changes." The more numerous discussions of limited scope are mostly based on insufficient data. Abundant material for investigations of this sort is now available.[30]

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[27] *Loc. cit.*, footnote 10.

[28] See, *e.g.*, C. A. Schott, *loc. cit.*; H. A. Hazen, "Variation of Rainfall West of the Mississippi River," *U. S. Signal Service Notes*, No. VII., 8vo, Washington, D. C., 1883, p. 8; also "Droughts in Kansas and Texas and Secular Variation in Rainfall," *Mo. Wea. Rev.*, Vol. 15, April, 1887, p. 119; Mark W. Harrington, *loc. cit.*, *Text*, pp. 19–20; *Atlas*, Sheet XXII., Map 4; J. D. Whitney, "Brief Discussion of the Question whether Changes of Climate can be brought about by the Agency of Man, and on Secular Climatic Changes in General, with Special Reference to the Arid Region of the United States," *The United States*, Suppl. I., Boston, 1894, Appendix B, pp. 290–317.

[29] See, *e.g.*, "Supposed Recent Changes in Climate" (by W. Upton and others), *Amer. Met. Journ.*, Vol. 7, June, 1890, pp. 79–81. (The records at New Bedford, Mass., from 1813, and at Providence, R. I., from 1831, show no progressive change in rainfall, but there are indications of a periodicity of about twenty years).

In the Temperate Zones most of the rain and snow comes, directly or indirectly, in association with general cyclonic storms. As the paths, numbers and intensities of these storms vary more or less from year to year, it is inevitable that the precipitation of any year, or of any month, may differ considerably from the general average for that period. Even a single heavy thundershower, or a well-developed general rainstorm may, for example, raise the total rainfall for a month 2 or 3 ins. above the normal. Such annual and monthly fluctuations of rainfall are well-known. They may result in giving a single year or month, or a series of them, wetter or drier than the average. The question whether there is any tendency towards a progressively decreasing or increasing rainfall anywhere in the United States, and whether there is any evidence of a periodic variation or oscillation in rainfall has in recent years been somewhat fully discussed by Professor A. J. Henry, and by Professor Eduard Brückner.

Henry plotted the "progressive averages of precipitation" for certain stations in southeastern New England, in the upper Ohio Valley (both for the years 1834–1896), and in the middle Mississippi Valley (1858–1896).[31] A rough periodicity of about nine years appears in the Ohio Valley curve. The curve for the middle Mississippi Valley shows little indication of periodicity. The New England curve shows a noticeable increase in rainfall, apparently a local phenomenon, from about 1845 on, with a climax in 1888–1889 (a drought period in 1880–1882 being excepted). It is apparent that the three curves are not in agreement as regards their periods of maximum and minimum. A later study of the departures from the normal of the annual rainfalls for all districts of the United States in the period 1887–1911 (25 years) "lends no color to the theory of a cycle in precipitation."[32] During the 25-year period under discussion, the tendency seems to have been towards years of deficient precipitation, although years of abundant rainfall were interspersed. Curves for selected stations in New England, the interior, the western Gulf, and North Carolina (1879–1911) show no "approach to uniformity of distribution in time or space." For the period and the districts under discussion, there were about equal numbers of dry and of wet years. Conditions favorable for unusually heavy rains over extended areas are apparently exceptional. Rainfalls close to or slightly below normal are rather to be expected.

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[30] See, *e. g.*, "Summaries of Climatological Data by Sections," U. S. Weather Bureau. (These Summaries contain the monthly and annual amounts of rainfall for each year throughout the period covered by the observations).

[31] Alfred J. Henry, *Bulletin D*, pp. 18–24, Pl. II.

[32] A. J. Henry, "Secular Variation of Precipitation in the United States," *Bull. Amer. Geog. Soc.*, Vol. 46, March, 1914, pp. 192–201.

Brückner has shown that over the world as a whole warmer and drier periods alternate with periods which are cooler and moister in an oscillatory cycle of about 35 years from maximum to maximum.[33]

In the case of the United States, curves are given for stations in the upper Ohio Valley, the central portion of the Mississippi Valley and for New England. The rainfall for each year is taken as the average of the 10 years of which it is the center, *e. g.*, for the year 1835, the average of the years 1831–40 is taken. In all parts of the world which are represented in the curves, except New England,[34] there was a maximum of rainfall about 1845–50; a minimum about 1860–70; another maximum in the early '80's, followed by a decrease until the end of the last century. From the minimum of 1836 to the minimum of 1871 there were 35 years, and between the maximum of 1848 to that of 1882 there were 34 years. At present, there is a cool and moist period, the middle of which is to be looked for about 1920. These oscillations have been traced back over 700 years in Europe, and, in Brückner's opinion, there is no doubt that they will continue. The size and value of crops; movements of population, and other economic consequences have been shown to depend upon these cycles. Thus, the maximum of rainfall about 1880 was followed by the "boom" on the High Plains, and the collapse of the same "boom" occurred when the succeeding dry period came on. Obviously, oscillations of rainfall will have their most far-reaching effects in regions over which the normal precipitation is barely enough for the ordinary needs. Here a fluctuation on one side or the other of the mean is of critical importance. Brückner has shown that in the most continental climates the difference between the maximum and the minimum rainfalls may amount to 25 per cent., or even 50 per cent. or more. The oscillations in the level of Great Salt Lake show no permanent change. The waters of the lake rise and fall with a periodicity which agrees in general with the Brückner 35-year cycle. After the close of the dry period following the middle of the last century, the lake rose more than 12 feet up to about 1880, its maximum coming during a wet period. Then it fell again during the next dry period, and rose during the present wet cycle.

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[33] Edward Brückner, "Klimaschwankungen seit 1700, nebst Beobachtungen über die Klimaschwankungen der Diluvialzeit," Vienna, 1890, pp. 324; "Zur Frage der 35-jährigen Klimaschwankungen," *Pet. Mitt.*, Vol. 48, 1902, pp. 173–178; "Klimaschwankungen und Völkerwanderungen im XIX Jahrhundert," *Internat. Wochenschr. f. Wissenschaft, Kunst und Technik*, 1910, March 5, pp. 15 (Berlin); "The Settlement of the United States as controlled by Climate and Climatic Oscillations," *Memorial Volume of the Transcontinental Excursion of 1912 of the Amer. Geog. Soc. of New York*, Large 8vo, New York, 1915, pp. 125–139.

[34] In the case of New England, the recent maxima came in 1869 and 1889, the conditions being different from those inland because of marine control.

Secular Variations in Rainfall: Non-instrumental Evidence.—Climatologists who take a broad view of their subject are interested in any facts which may throw light on the question of secular variations in rainfall. They agree, however, in the conviction that non-instrumental evidence is to be regarded as in a wholly different category from that of actual rain-gauge records in that the former can not possibly be subjected to the same rigid analysis and scrutiny as is the case with the latter.

Within the last few years, Professors A. E. Douglass and Ellsworth Huntington have made a study of the "rings" of trees in Arizona and in California, it being assumed that the thickness of the annual layers of tree-growth gives an approximate measure of the annual amount of precipitation. Douglass has measured the rings of yellow pines on the northern Arizona plateau, and finds a correlation between tree growth and certain meteorological cycles.[35] By means of an empirical formula, a test was made covering a period of over 40 years for which actual rainfall records are available, and it was found that the rings gave a measure of the rainfall with an average accuracy of over 70 per cent.[36] Indications of periods of 11.4,

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[35] A. E. Douglass, "Weather Cycles in the Growth of Big Trees," *Mo. Wea. Rev.*, Vol. 37, 1909, pp. 225–237; "A Method of Estimating Rainfall by the Growth of Trees," *Bull. Amer. Geog. Soc.*, Vol. 46, May, 1914, pp. 321–335; "Pine Trees as Recorders of Variations in Rainfall," *Astron. and Astrophys. Soc. Amer.; Bull. Internat. Insti. Agri.*, abstract in *Quart. Journ. Roy. Met. Soc.*, Vol. 39, July, 1913, pp. 244–245. F. E. Clements and A. E. Douglass: "Climatic Cycles," *Yearbook Carnegie Institution*, Washington, D. C., 1918, p. 295. (Discusses coincidence of drought in the Southwest with years of maximum sunspots, and mentions further tree-ring examinations to be made with this in mind). See also footnote 37, later.

[36] In the case of the older trees, certain corrections were applied.

21 and 33.8 years, as well as of still longer fluctuations, were found. The last crest of the 33–34 year period, about 1900, can be correlated with the Brückner period above referred to.

The results obtained by Douglass have been included by Huntington in a very considerable investigation of the various kinds of evidence of climatic "changes" during the past 3,000 years in the arid southwest. This investigation involved a study of the rings of the "Big Trees" of California; and of prehistoric ruins; archeological remains; strand lines, dunes and alluvial terraces in southern Arizona and New Mexico.[37] A comparison of the curves showing the rapidity of growth of the "Big Trees" with curves previously plotted, illustrating changes of climate in Central and Western Asia, leads Huntington to the conclusion that there is a correspondence between them back as far as 1200 B.C., the agreement being especially pronounced during the period 300–1000 A.D. There are, however, also cases of a lack of correspondence between the curves. The archeological and physiographic evidence seems to Huntington to indicate three periods during which a much larger population was living in the southwest than seems to be possible at present, owing to the existing deficiency of water supply. These three population eras were about 1200 B.C., and in the seventh and thirteenth centuries A.D., and correspond with three long wet periods suggested by the studies of the tree rings made by Douglass and Huntington.

The Climatologist's Attitude regarding Non-instrumental Evidence of Climatic Changes.—Climatologists as a group do not feel competent to weigh such facts as those adduced by Huntington and others regarding climatic oscillations long before the days of instrumental records. They realize that the proper understanding and critical analysis of botanical, archeological and physiographic evidence requires a degree of technical knowledge which is usually not a part of their own scientific equipment. Therefore it must be left to the experts to weigh this evidence and to determine its value. In connection with this, it may be stated that these experts are by no means unanimous in their views. It has, *e. g.*, been pointed out that the growth of tree rings may be affected by many conditions other than the annual rainfall. The distribution of precipitation through the year exercises a more critical control than the annual amount, while the age of the tree; normal cycles in the tree's growth; insect and other pests, often themselves coming periodically; overcrowding; the loss of shelter, and other factors must be taken into account. Furthermore, the determination of the proper "correction factor" in plotting the curves may not be as simple a matter as it seems. The fact that the "Big Trees" have continued to thrive for 3,000 years has been taken to indicate a remarkable uniformity of climatic conditions, rather than a series of oscillations. Again, there is opposition among geologists to the view that variations in erosion and in lake levels, due to variations in rainfall, furnish the proper explanation of the conditions which have been observed in the dunes, strand lines and alluvial terraces. In a region of active mountain growth, like the southwest, elevation of the land may explain the facts whose interpretation has been sought in climatic change. Lastly, the archeological evidence is by no means regarded as conclusive by all the experts. Thus, J. W. Fewkes and others believe that long-continued prehistoric irrigation, leading to increasing salinity of the soil, was perhaps more potent in causing human migrations than human enemies or increasing aridity.[38] Migration in search of firewood, and invasions of enemy tribes, as well as a reduction in the fertility of the soil, may help to explain these prehistoric changes of population.

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[37] Ellsworth Huntington, "The Fluctuating Climate of North America," *Geogr. Journ.*, Vol. 40, September–October, 1912, pp. 264–280, 392–411 (abridged and reprinted in *Smithson. Inst. Ann. Report for 1912*, Washington, D. C., 1913, pp. 257–268); "The Shifting of the Climatic Zones as Illustrated in Mexico," *Bull. Am. Geogr. Soc.*, 1913, Vol. 45, 1–12; *Geogr. Journ.*, Vol. 41, June, 1913; "Secret of the Big Trees, Yosemite, Sequoia and General Grant National Parks," *Pub. U. S. Dept. of the Interior*, 1913, 24 pp., 14 figs.; "The Secret of the Big Trees," *Harper's Mag.*, July, 1912. See especially "The Climatic Factor as Illustrated in Arid America," by Ellsworth Huntington, with contributions by Charles Schuchert, Andrew E. Douglass and Charles J. Kullmer. *Publ. of the Carnegie Inst. of Washington*, No. 192, 4to, Washington, D. C., pp. iii and 341.

In the face of such conflicting testimony on the part of the experts, the conservative climatologist may well remain open-minded on this whole question.

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[38] J. W. Fewkes, 28th *Am. Rept. Bur. Amer. Ethn.*, 1906–07 (1912). There is abundant literature on the archeology of the southwest. See, *e. g.*, the following recent publications: E. L. Hewett, J. Henderson and W. W. Robbins, "The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture," *Bulletin 54, Smithsonian Inst., Bur. Amer. Ethn.*, 8vo, Washington, D. C., 1913, pp. 76 (pp. 41–70 on climate and the evidence of climatic changes. A progressive desiccation of the region since the beginning of the pueblo and cliff-dwelling period is thought to be indicated, but the change in population may possibly be ascribed to other causes). Harold S. Colton: "The Geography of Certain Ruins near the San Francisco Mountains, Arizona," *Bull. Geogr. Soc. Phila.*, Vol. 16, April, 1918, pp. 1-24. (Discusses the ruins as affording evidence of climatic oscillations. "The question can not be finally settled until much more work has been done in the pueblo region").